Recent Heavy Flavors results from Tevatron

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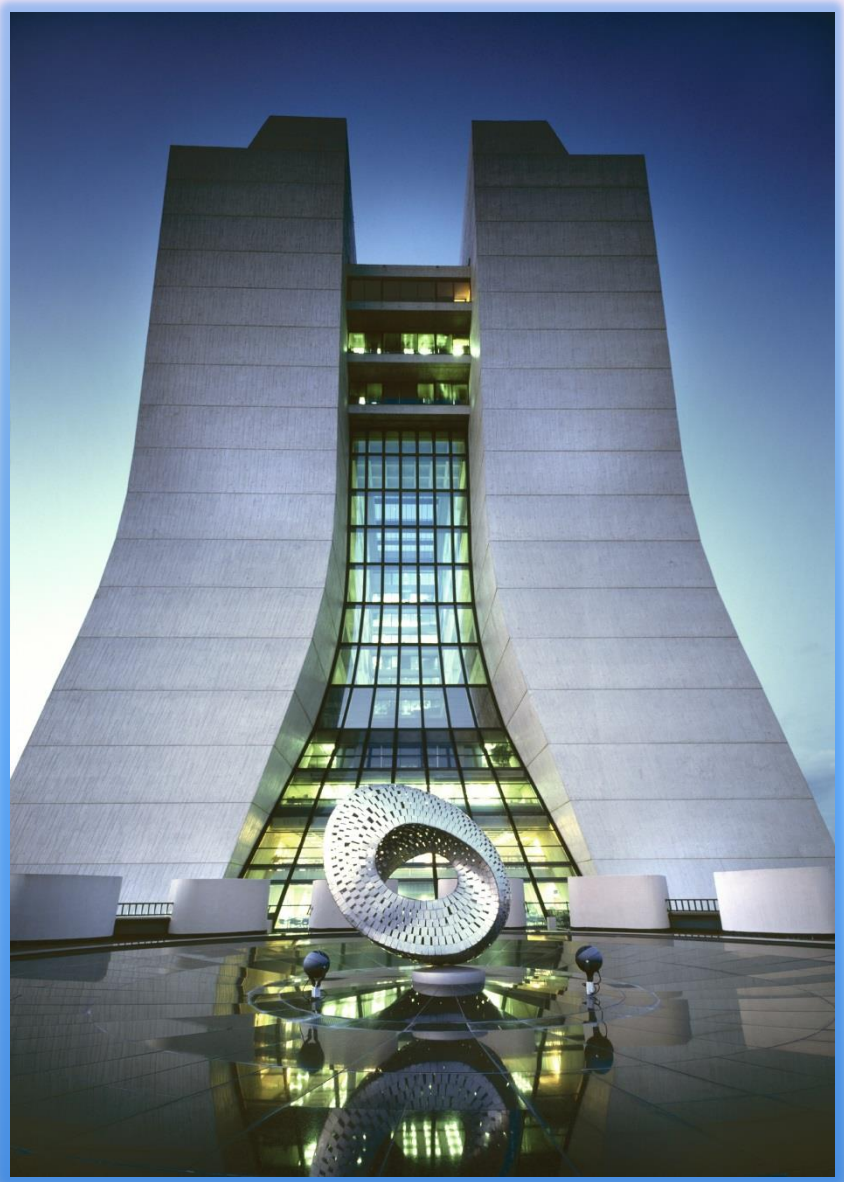
on behalf of the CDF and DØ Collaborations

March 27, 2017

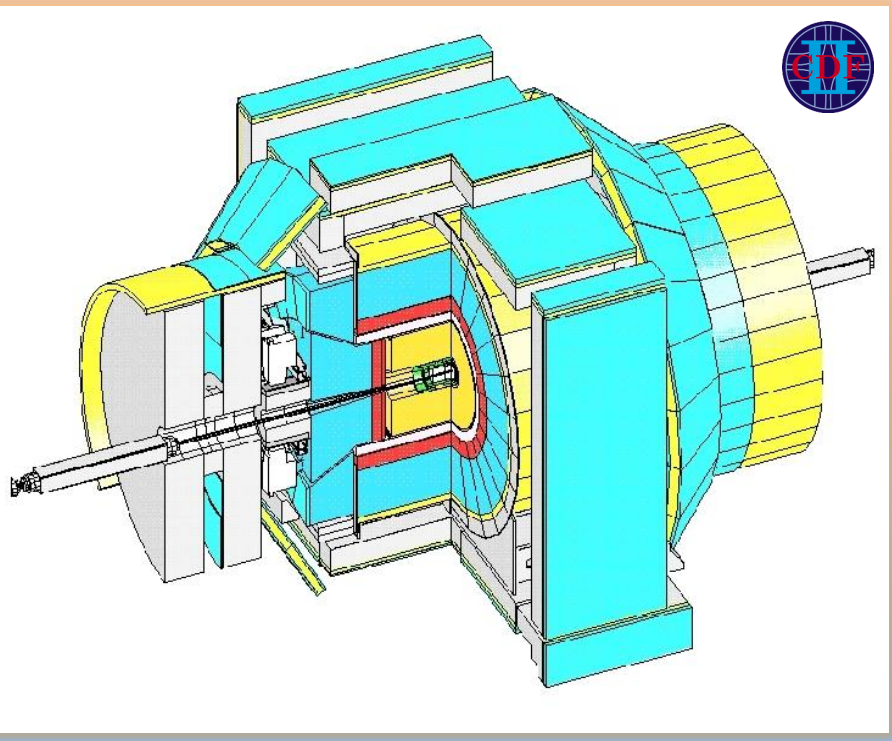
Outline

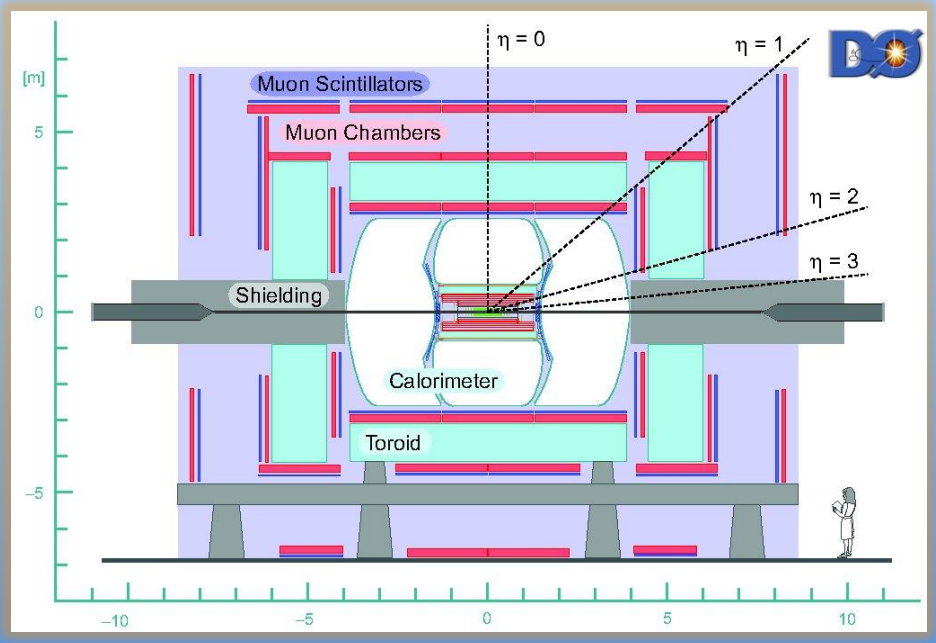
- Tevatron, CDF and DØ
- Confirmation of the X(5568) with semileptonic decays of B_s meson
- Search for exotic baryons decaying to $J/\psi\ \Lambda$ pairs
- Measurement of D^+ - meson production cross section at low p_T
- Conclusion



Tevatron, CDF and DØ

- $p\bar{p}$ collider
- $\sqrt{s} = 1.96$ TeV
- In operation from 2001 to 2011 (Run II)
- Total integrated Luminosity delivered: ~ 12 fb^{-1} (~ 10 fb^{-1} for physics analysis)

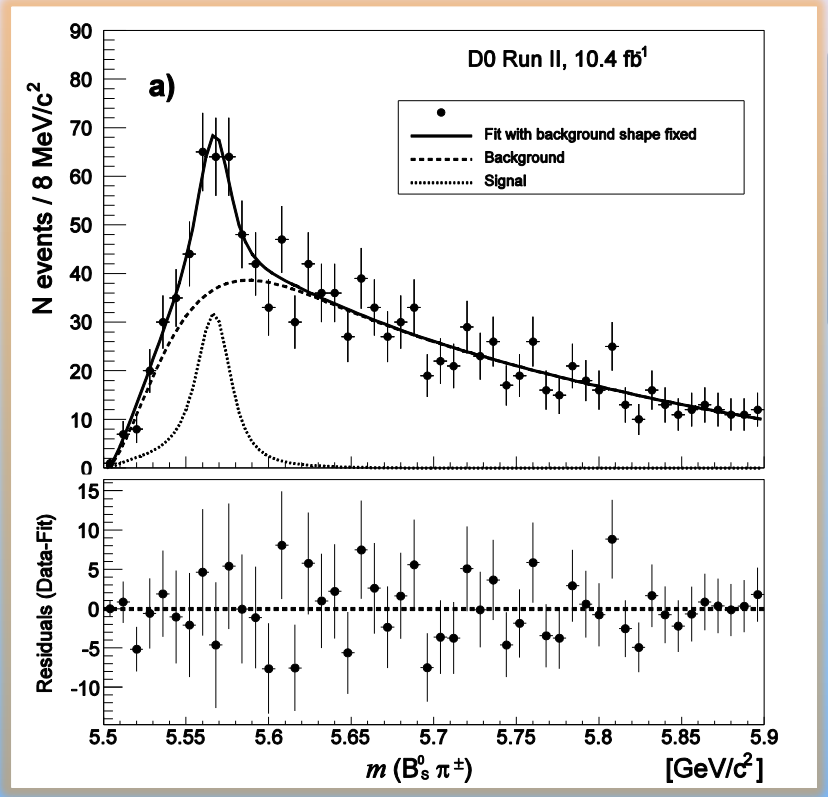




- Two general purpose experiments: CDF and DØ
- Large coverage and good performance of vertex, tracking, calorimeter and muon spectrometers
- Unique results ($p\bar{p}$ collisions, low pileup, unique energy range)

Evidence for $B_s\pi$ state, $B_s \to J/\psi\,\phi(1020)$

V.M. Abazov et al (D0 Collaboration), Phys. Rev. Lett. 117, 022003 (2016)



X(5568)

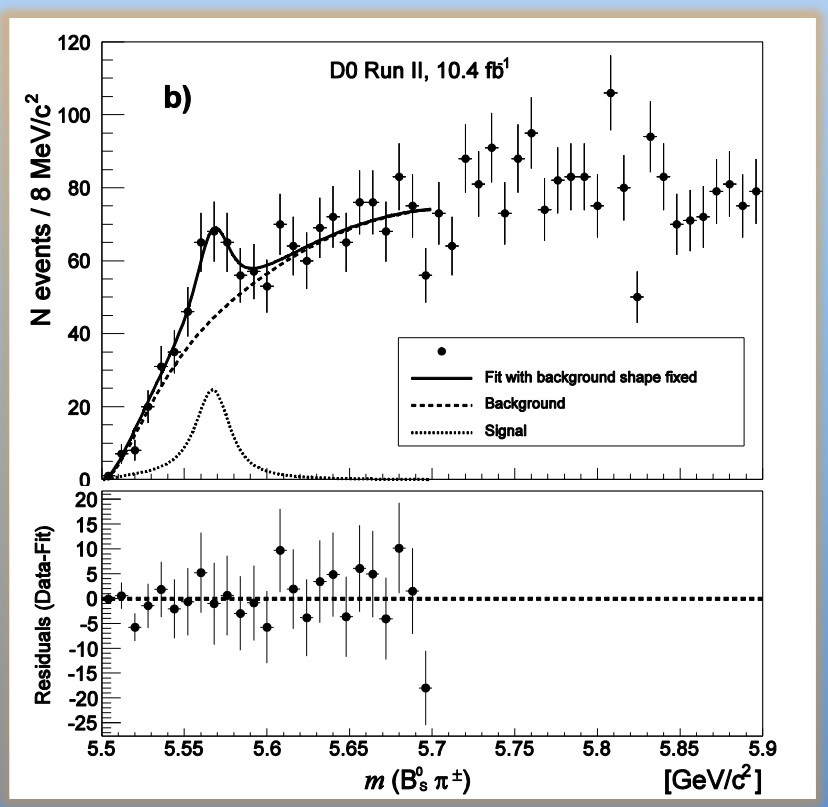
$$M = 5567.8 \pm 2.9(\text{stat})^{+0.9}_{-1.9}(\text{syst})\,\text{MeV}/c^2$$

$$\Gamma = 21.9 \pm 6.4(\text{stat})^{+5.0}_{-2.5}(\text{syst})\,\text{MeV}/c^2$$

$$\rho(X(5568)/B_s) = 8.6 \pm 1.9(\text{stat}) \pm 1.4(\text{syst})\%$$

← ΔR cut

No ΔR cut →



Statistical significance (with systematics and LEE)

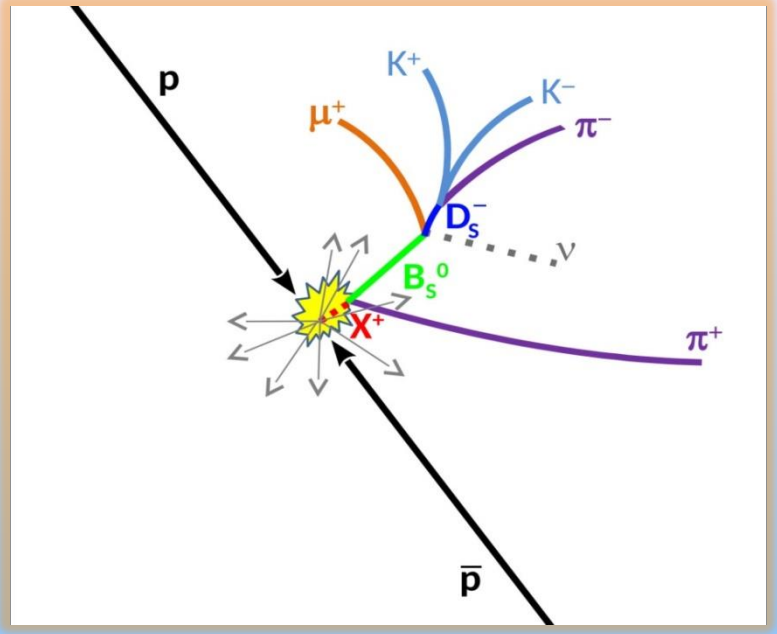
With $\Delta R = \sqrt{\Delta\eta(B_s,\pi) + \Delta\phi(B_s,\pi)} < 0.3$ cut:

5.1σ

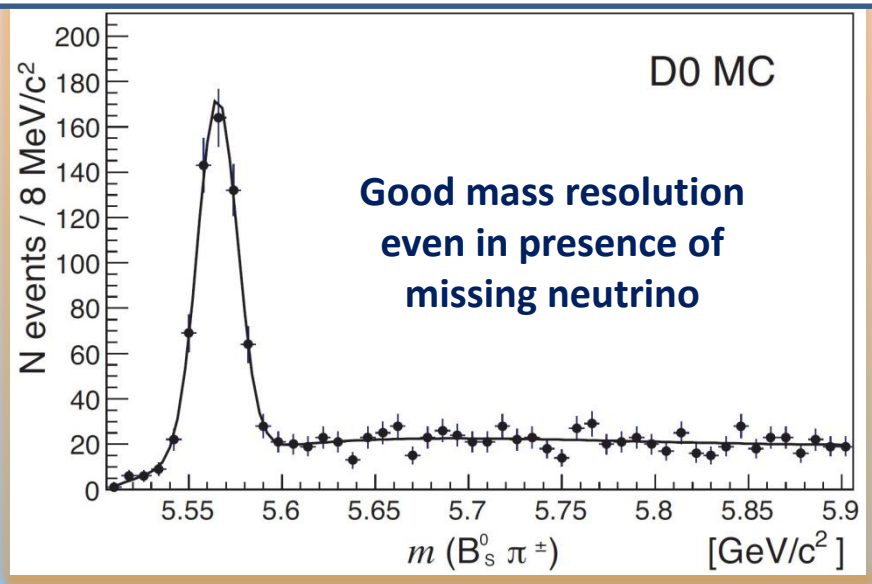
Without ΔR cut: 3.9σ

Not seen by LHCb and CMS in pp collisions at 7 and 8 TeV/c^2.

X(5568)→$B_s\pi$ with semileptonic decays of the B_s mesons



$X(5568) \to B_s \pi,\ B_s \to D_s \mu X_{any},\ D_s \to \phi(1020)\,\pi$



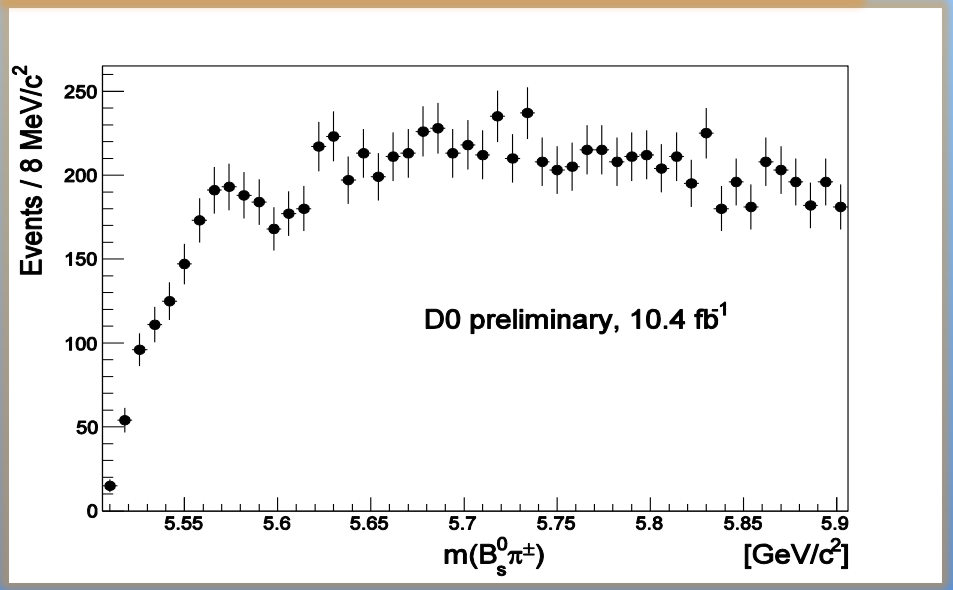
Event reconstruction and selection

D0 Run II integrated luminosity 10.4 fb^{-1}

$3 < p_T(\mu) < 25$ GeV/c; $p_T(K) > 1$ GeV/c;
$1.012 < M(KK) < 1.03$ GeV/c^2
$4.5 < M(D_s\mu) < M(B_s)$; $p_T(D_s\mu) > 10$ GeV/c

$M(B_s\pi) = M(D_s\mu\pi) - M(D_s\mu) + M(B_s)$,
where $M(B_s) = 5.3667$ GeV/c^2

$5.506 < M(B_s\pi) < 5.906$ GeV/c^2



$X(5568) \to B_s\pi$ with semileptonic decays of the B_s mesons

Background parametrization

Background distribution is obtained from MC and reweighted to data.

$F_{bgr}(M)=(C_1 \cdot m+C_2 \cdot m^2+C_3 \cdot m^3+C_4 \cdot m^4)\times \exp(C_5 \cdot m+C_6 \cdot m^2)$, where $m=M-M_{thr}$

Several alternative parametrizations of the background were used to model the background for background shape systematics estimation.

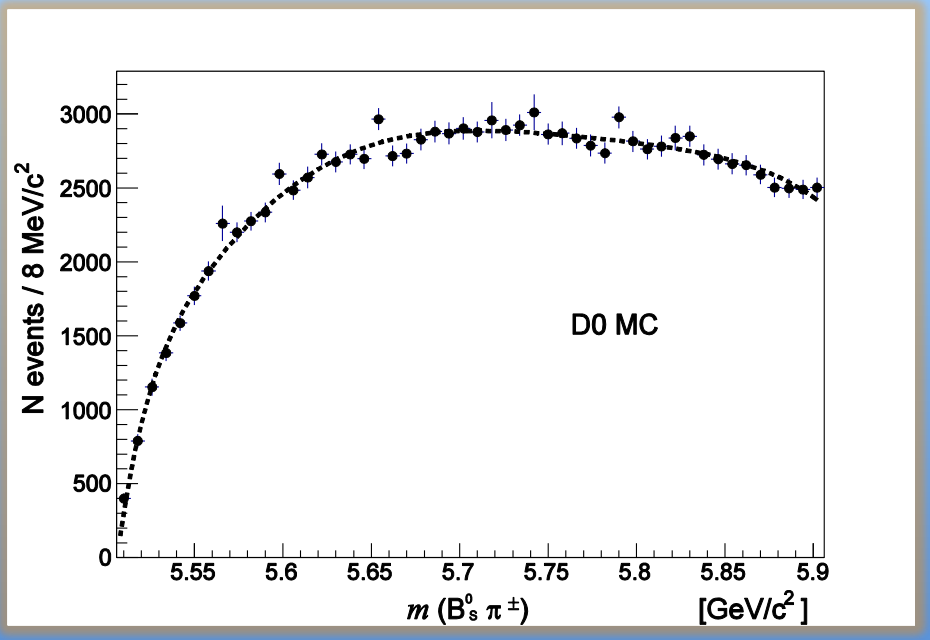
Fit to data

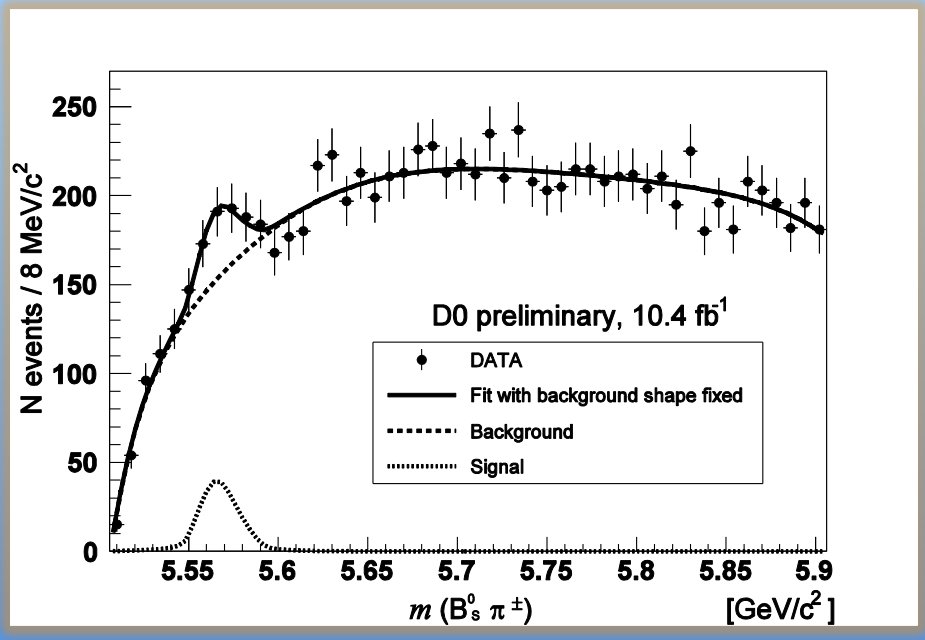
$F_{fit}(M,M_x,\Gamma_X)=f_{bgr} \cdot F_{bgr}(M)+f_{sig} \cdot F_{sig}(M,M_x,\Gamma_X)$

where $F_{sig}(M,M_x,\Gamma_X)$ - S-wave BW function convoluted with resolution (including missing neutrino effect), f_{bgr}, f_{sig} - normalization coefficients.

$$M_x = 5566.7^{+3.6}_{-3.4}\ \text{MeV/c}^2$$

$$\Gamma_x = 6.0^{+9.5}_{-6.0}\ \text{MeV/c}^2,\ N_{ev} = 139^{+51}_{-63}$$





X(5568)→$B_s\pi$ with semileptonic decays of the B_s mesons

Local statistical significance

$$\sqrt{-2 \cdot \ln \frac{\mathcal{L}_0}{\mathcal{L}_{\max}}}$$

4.5σ from the fit, 3.2σ with the systematic uncertainties.

Systematic uncertainties

Background shape description, background reweighting, B_s mass scale (MC and data), detector resolution and missing neutrino effect, P-wave Breit-Wigner.

Comparison with hadronic channel

	Semileptonic	Hadronic, ΔR cut	Hadronic, no ΔR cut
Fitted mass, MeV/c^2	$5566.7^{+3.6\ +1.0}_{-3.4\ -1.0}$	$5567.8 \pm 2.9^{+0.9}_{-1.9}$	5567.8
Fitted width, MeV/c^2	$6.0^{+9.5\ +1.9}_{-6.0\ -4.6}$	$21.9 \pm 6.4^{+5.0}_{-2.5}$	21.9
Fitted number of signal events	$139^{+51\ +11}_{-63\ -32}$	$133 \pm 31 \pm 15$	106 ± 23

Results in semileptonic channel are compatible with those in hadronic channel within uncertainties.

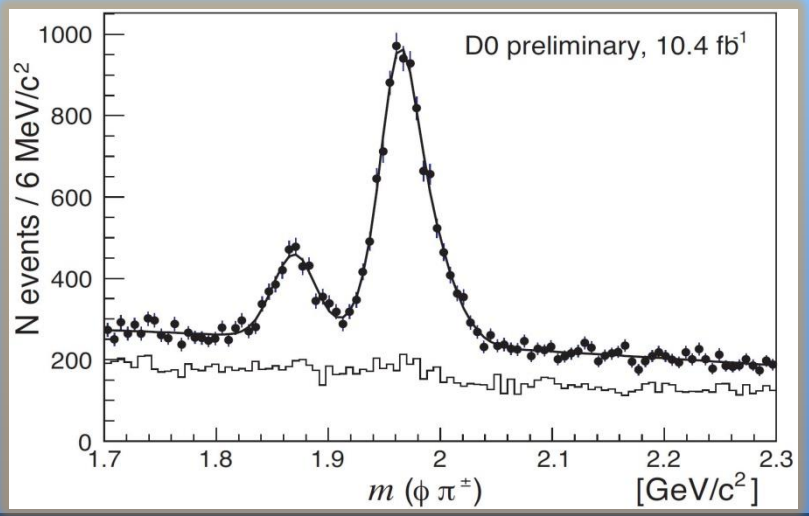
X(5568)→$B_s\pi$ with semileptonic decays of the B_s mesons

	Semileptonic	Hadronic, ΔR cut	Hadronic, no ΔR cut
Local significance	4.5σ	6.6σ	4.8σ
Significance with systematics	3.2σ	5.6σ	-
Significance LEE+systematics	-	5.1σ	3.9σ

Combined significance

$$p_{comb} = p_{sl} \cdot p_{had} \cdot [1 - \ln(p_{sl} \cdot p_{had})],$$

$p_{comb} = 5.6 \cdot 10^{-9}$ ($1.1 \cdot 10^{-6}$ without ΔR cut) which corresponds to combined significance 5.7σ (4.7σ without ΔR cut)



Production ratio of X(5568) to B_s

Calculated by fitting $M(\phi\pi)$ distributions in the opposite sign and same sign $D_s\,\mu$ samples.

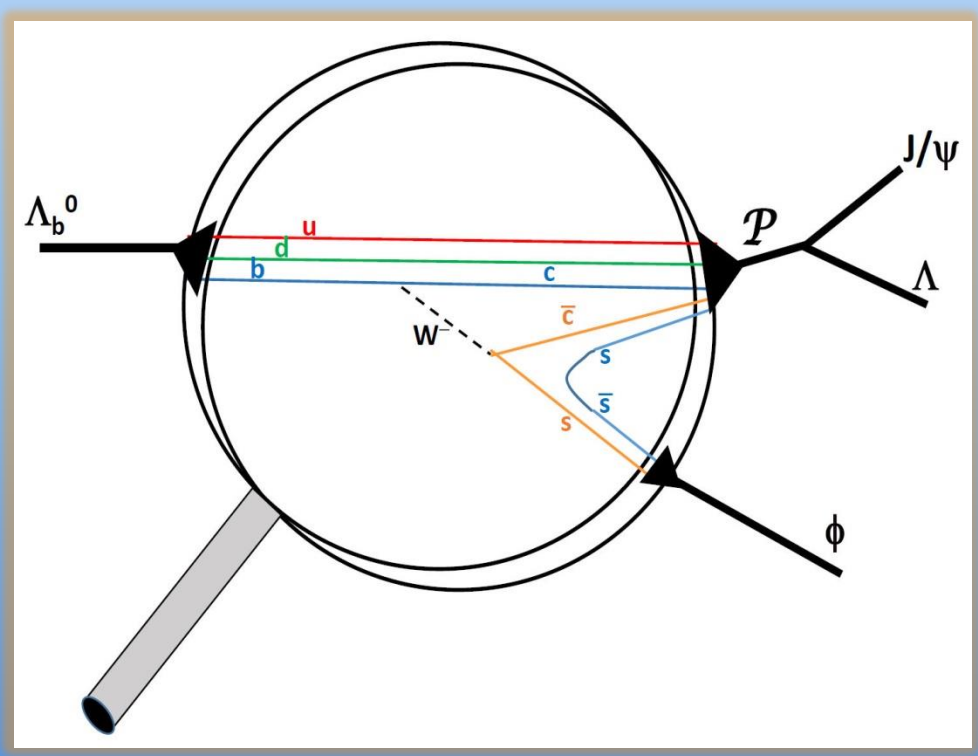
$$\rho(X(5568)/B_s) = 7.3^{+2.8}_{-2.4}(stat)^{+0.6}_{-1.7}(syst)\%$$

which is in agreement with the ratio measured in the hadronic channel.

Search for exotic baryons decaying to $J/\psi\ \Lambda$

- Observation of two J/ψ p states named P_c around 4380 MeV/c^2 and 4450 MeV/c^2 in $\Lambda_b \rightarrow J/\psi$ p K^- decays reported by LHCb.
- Numerous states with the quark contents including $c\bar{c}$ pair and three light quarks are expected to exist within 500 MeV of the J/ψ p threshold.

Search in the $M(J/\psi\ \Lambda)$, where $J/\psi \rightarrow \mu\mu$, $\Lambda \rightarrow p\pi^-$.



Event reconstruction

D0 Run II integrated luminosity 10.4 fb^{-1}

$p_T(\mu) > 1$ GeV/c; $p_T(\mu\mu) > 4$ GeV/c

$2.92 < M(\mu\mu) < 3.25$ GeV/c^2

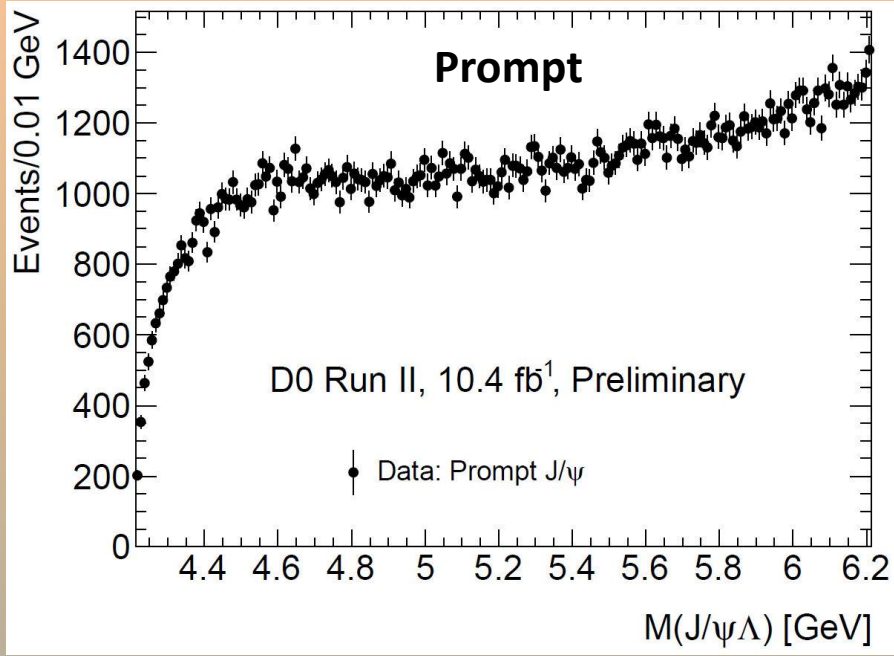
$p_T(\Lambda) > 0.7$ GeV/c

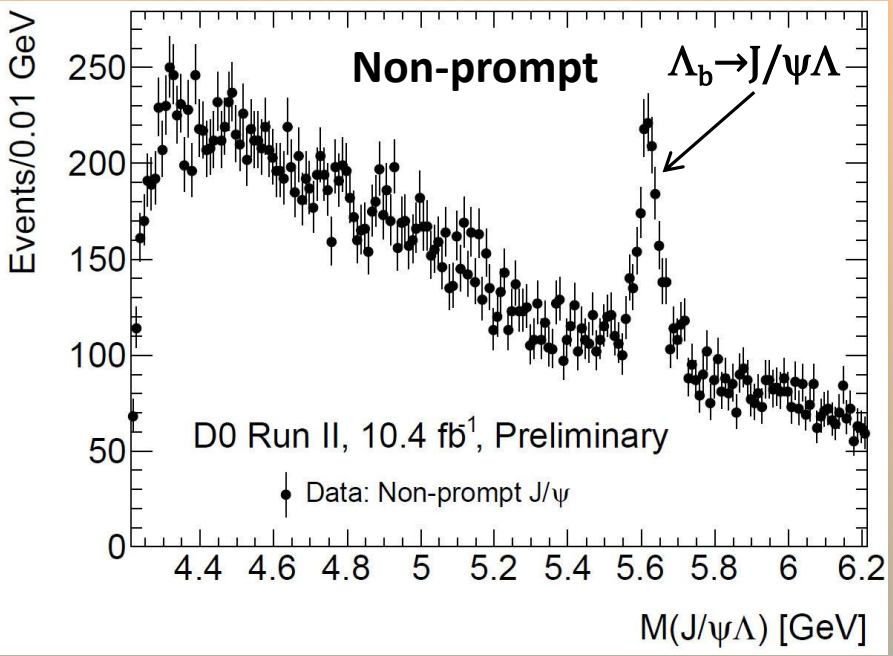
$1.110 < M(\Lambda) < 1.122$ GeV/c^2

$p_T(\pi) > 0.15$ GeV/c

Non-prompt: J/ψ decay length significance in the transverse plane is greater than 3 and Λ decay vertex is closer to J/ψ decay vertex than to the primary vertex.

Search for exotic baryons decaying to $J/\psi\,\Lambda$





Search procedure

Binned maximum likelihood fits to the distribution of the $J/\psi\,\Lambda$ invariant mass in the range from the $J/\psi\,\Lambda$ threshold to 4.7 GeV/c².

$$F_{fit}(M,M_x,\Gamma_x)=f_{bgr}\cdot F_{bgr}(M)+f_{sig}\cdot F_{sig}(M,M_x,\sigma_x),$$

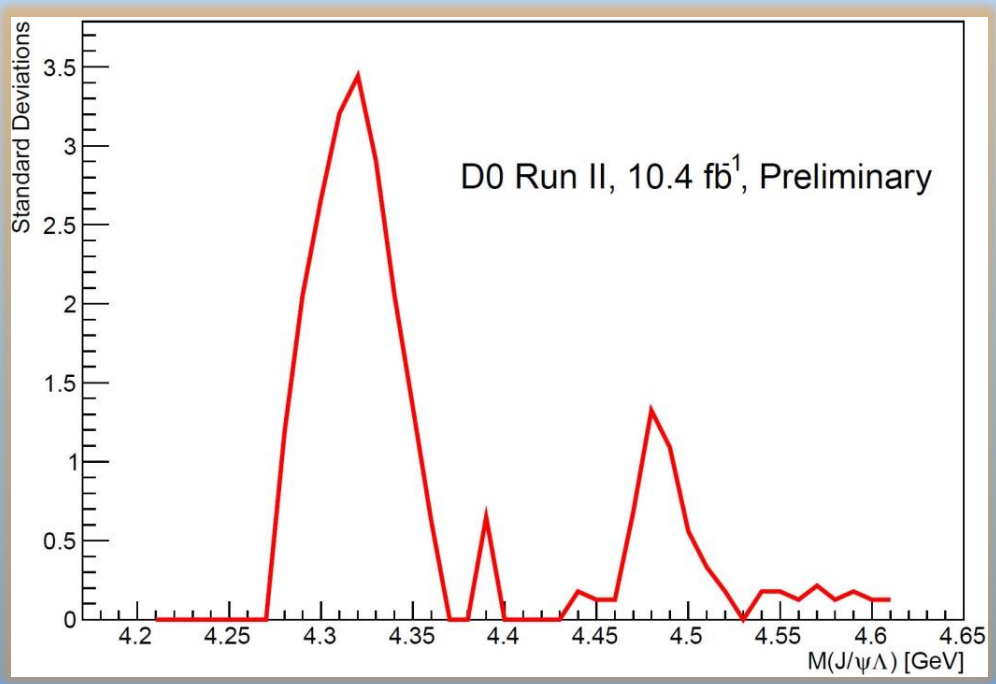
where $F_{sig}(M,M_x,\sigma_x)$ - Gaussian function with free M_x, σ_x; f_{bgr}, f_{sig} - normalization coefficients.

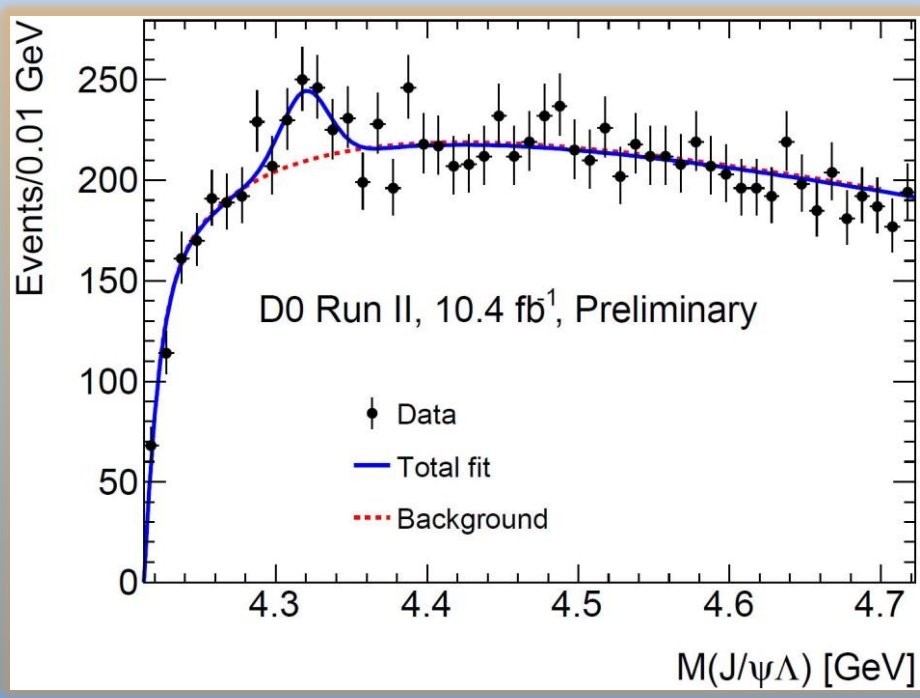
$$F_{bgr}(M) \propto M\cdot(M^2/M_{thr}^2-1)^{c_1}\cdot e^{-c_2 M}\cdot(1-e^{-(M-M_{thr})/b}),$$

where M_{thr} is the $J/\psi\,\Lambda$ threshold

Search for exotic baryons decaying to $J/\psi\ \Lambda$

Mass fits of the sum of signal + background or background only to the data were performed with the signal mass set at fixed values in 10 MeV steps. Local statistical significance is defined as $\sqrt{-2 \cdot \ln\left(\mathcal{L}_0/\mathcal{L}_{\max}\right)}$. The highest local significance of **3.45σ** occurs at **M = 4.32 GeV/c²**. If LEE (computed in the same 500 MeV interval) is taken into account it leads to the global significance of **2.8σ**.





No evidence for new baryons decaying to $J/\psi\ \Lambda$

Measurement of D^+-meson production cross section at low p_T

- Test and refine QCD models at small momentum transfer.
- Improved estimation of background rates from neutrinos produced in decays of charm hadrons from cosmic-ray interactions with atmospheric nuclei.
- Previous measurements in $p\bar{p}$ collisions were restricted to mesons with $p_T > 6$ GeV/c.

$D^+ \to K^- \pi^+ \pi^+$, $p_T(D^+) > 1.5$ GeV/c

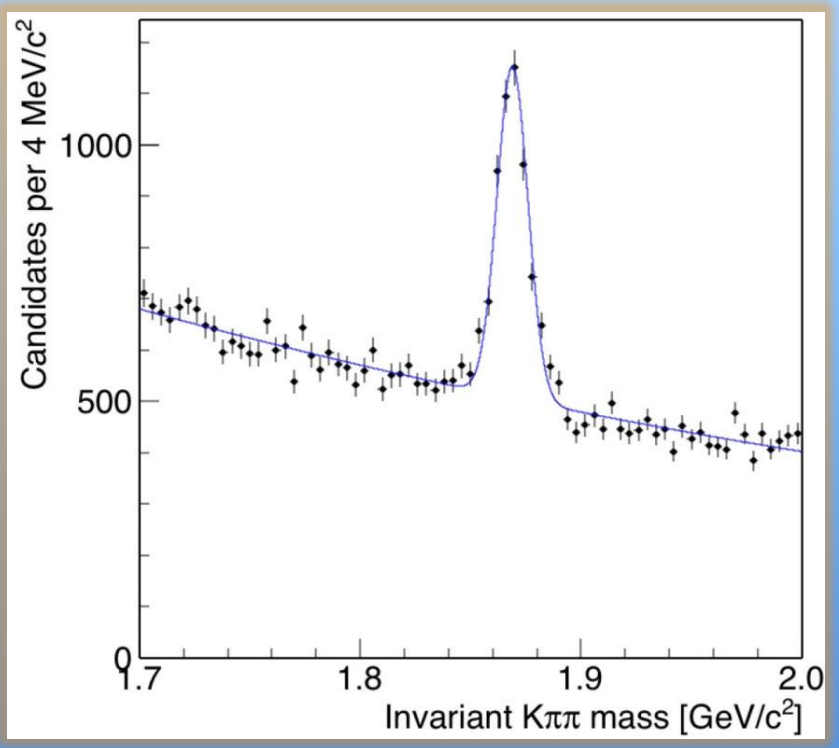
5 p_T bins: 1.5-2.5, 2.5-3.5, 3.5-4.5, 4.5-6.5, 6.5-14.5 GeV/c

$$\sigma_i = \frac{N_i/2}{\int \mathcal{L}dt \cdot \epsilon_i \cdot \mathcal{B}}$$

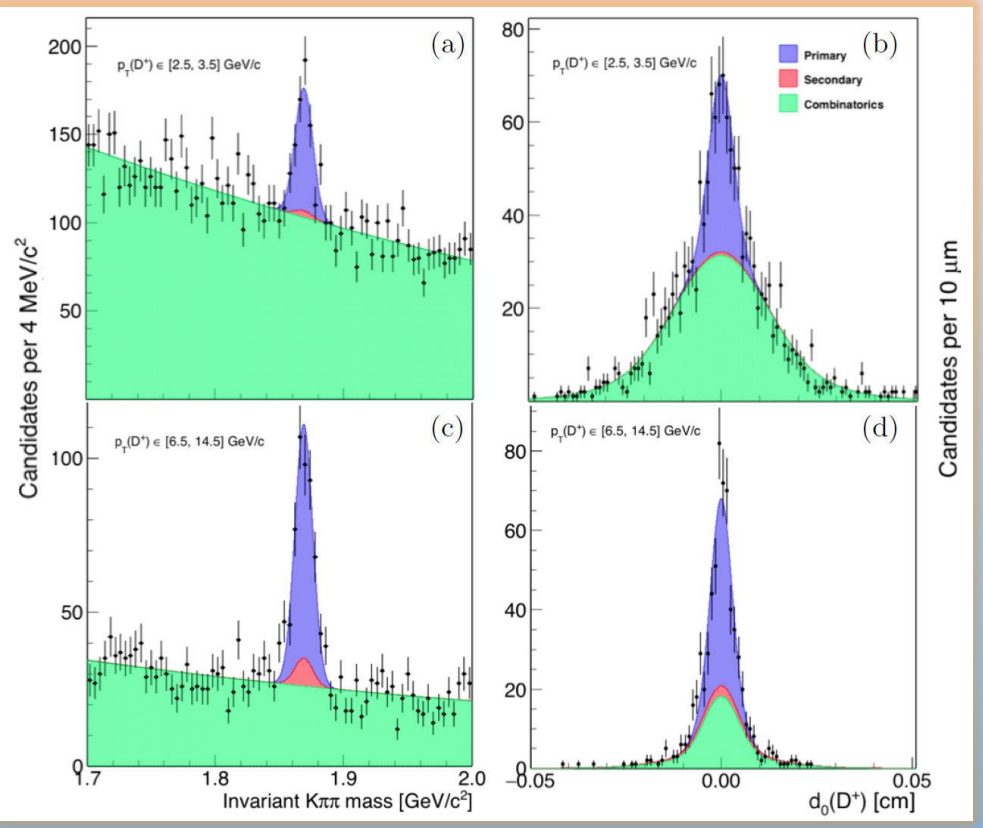
CDF Run II integrated luminosity 10 fb^{-1}

Zero and minimum bias triggers were used.

Rapidity interval: $|y| < 1$



Measurement of D^+-meson production cross section at low p_T



In each p_T bin the yields of primary (from $p\bar{p}$ interaction or excited charm resonances), secondary (from b-hadron decays) D^+ decays and combinatorial background were determined from simultaneous ML fit to the unbinned distributions of $M(K^- \pi^+ \pi^+)$ and D^+ impact parameter.

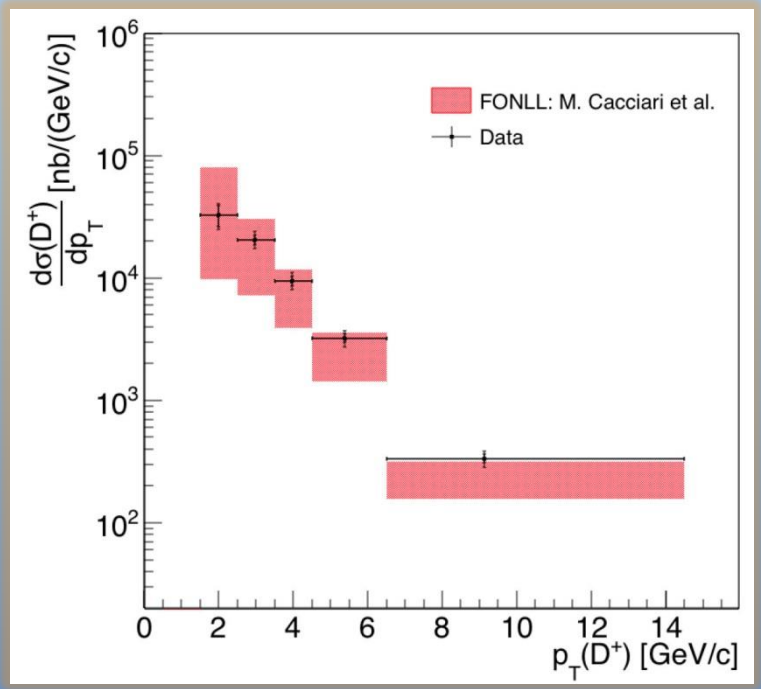
2950 primary D^+ are obtained from the fit.

Efficiency ϵ_i which includes detection, reconstruction and selection efficiencies, varies from 0.27 to 7.5% depending from p_T bin.

Main systematic uncertainties: primary D^+ yield (0.9-1.5%), silicon detector efficiencies (11.5%).

Measurement of D^+-meson production cross section at low p_T

p_T range (GeV/c)	Eff. p_T (GeV/c)	$d\sigma(D^+, \lvert y\rvert < 1)/dp_T$ (μb/GeV/c)	$\sigma_i(D^+, \lvert y\rvert < 1)$ (μb)
$1.5 - 2.5$	1.99	$32.7 \pm 6.5 \pm 4.2$	$32.7 \pm 6.5 \pm 4.2$
$2.5 - 3.5$	2.97	$20.6 \pm 1.8 \pm 2.7$	$20.6 \pm 1.8 \pm 2.7$
$3.5 - 4.5$	3.97	$9.50 \pm 0.84 \pm 1.2$	$9.50 \pm 0.84 \pm 1.2$
$4.5 - 6.5$	5.37	$3.23 \pm 0.26 \pm 0.42$	$6.46 \pm 0.52 \pm 0.84$
$6.5 - 14.5$	9.14	$0.34 \pm 0.04 \pm 0.04$	$2.69 \pm 0.22 \pm 0.35$



"Eff. p_T" : p_T at which the point-value of cross section equals the predicted p_T-averaged value over the bin.

The total fiducial cross section, obtained by summing over all p_T bins, is:

$71.9 \pm 6.8(\text{stat}) \pm 9.3(\text{syst})$ μb

$1.5 < p_T(D^+) < 14.5$ GeV/c, $|y| < 1$

Conclusion

- $X(5568) \rightarrow B_s\pi,\ B_s \rightarrow D_s\mu\ X$. There is an excess of events in the data consistent with the decay $X(5568) \rightarrow B_s\pi,\ B_s \rightarrow J/\psi\ \phi$ which was previously reported by D0. The mass, natural width and production rates in the semileptonic and hadronic channels are consistent. Combined significance for semileptonic and hadronic channels is 5.7σ.

  https://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/B/B68/

- Search for exotic baryons $\rightarrow J/\psi\ \Lambda$. In the mass range between threshold and 4.7 GeV/c^2 no evidence for new baryons decaying to $J/\psi\ \Lambda$ have been found, the most significant deviation from background-only hypothesis is seen at $M(J/\psi\ \Lambda) = 4.32$ GeV/c^2 with a global significance (including LEE) 2.8σ.

  https://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/B/B69/

- D^+-meson production cross section measurement down to D^+ p_T 1.5 GeV/c. This is unique result in that it probes strong-interaction dynamics in a range unexplored in charm production from $p\bar{p}$ collisions. While the measurements lie within the band of theoretical uncertainty, differences in shape suggest that theoretical predictions can benefit by taking into account these results

  T. Aaltonen et al . (CDF Collaboration), arXiv:1610.08989 [hep-ex]

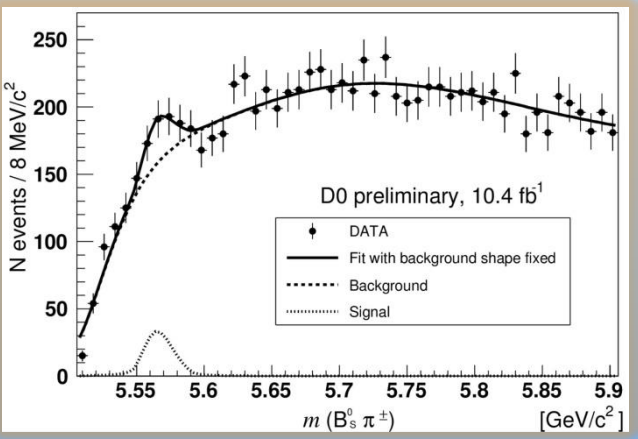
Backup slides

$X(5568) \to B_s\pi$ with semileptonic decays of the B_s mesons

Alternative background parametrizations

1. $F_{bgr}(M)=(C_1+C_2\cdot m^2+C_3\cdot m^3+C_4\cdot m^4)\times\exp(C_5\cdot m+C_6\cdot m^2)$, where $m=M-\Delta$, $\Delta=5.5$ GeV/c^2.
2. $F_{bgr}(M) = M\cdot\left(\frac{M^2}{M_{thr}^2}-1\right)^{C_1}\times\exp(C_2\cdot M)$, where M_{thr} is a $B_s\pi$ threshold.
3. Histogram smoothing (one iteration of 353QH algorythm).

(1)



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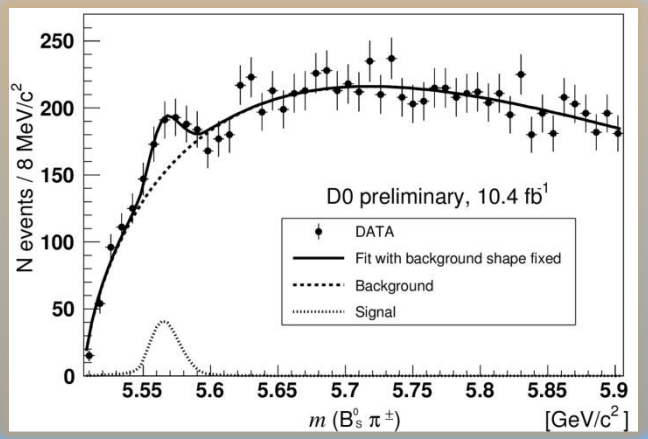

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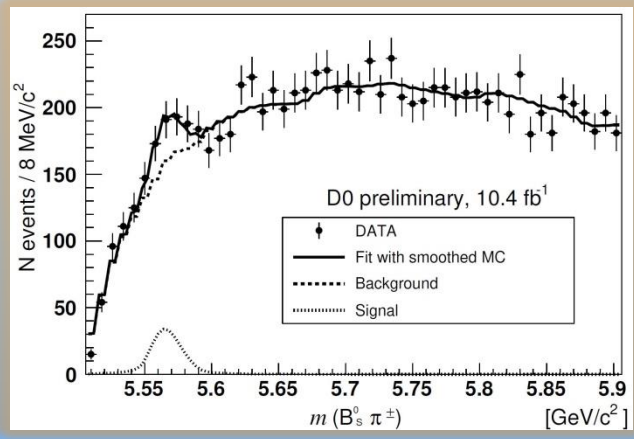

	Parametrization (1)	Parametrization (2)	Parametrization (3)
Fitted mass, MeV/c^2	$5566.2^{+4.2}_{-4.1}$	$5566.0^{+3.6}_{-3.4}$	5564^{+5}_{-5}
Fitted width, MeV/c^2	$6.0^{+12.0}_{-6.0}$	$6.5^{+8.9}_{-6.5}$	10^{+17}_{-10}
Fitted number of signal events	$115.9^{+51.8}_{-47.7}$	$145.7^{+50.7}_{-54.3}$	136^{+59}_{-48}
Local significance	3.7σ	4.7σ	3.9σ

X(5568)→$B_s\pi$ with semileptonic decays of the B_s mesons

Systematic uncertainties

Source	mass, MeV/c^2	width, MeV/c^2	event yield, events
Background shape description	$+0.0$; -0.7	$+0.7$; -2.5	$+4.8$; -28.0
Background reweighting	$+0.1$; -0.1	$+0.7$; -0.7	$+5.0$; -5.0
B_s^0 mass scale, MC and data	$+0.3$; -0.5	$+1.0$; -1.4	$+7.5$; -9.6
Detector resolution	$+0.0$; -0.5	$+1.3$; -2.6	$+3.7$; -6.4
P-wave Breit-Wigner	$+0.0$; -0.2	$+0.0$; -2.4	$+0.0$; -7.0
Missing neutrino effect	$+1.0$; -0.0	-	-
Total	$+1.0$; -1.0	$+1.9$; -4.6	$+10.9$; -31.5